Clearing electrodes: Past experience, technological aspects and potential

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Outline

- Past experience with clearing electrodes
- Recent experiments in the PS
- Issues of highly resistive clearing electrodes
  - Impedance
  - Manufacturing
- Potential

Motivation

- In several simulations and experiments is has been shown that localized clearing electrodes can effectively suppress electron multipacting close to the electrode
- Distributed clearing electrodes could be used to fight the electron cloud effect over longer regions of an accelerator
- However, issues such as impedance, aperture and manufacturing get more important for larger lengths

Past experience with clearing electrodes

- We have to discriminate between ion clearing and electron cloud clearing
- One example for ion clearing is the CERN AA (antiproton accumulator) machine where large stacks of p-bars had to be kept. The AA clearing system started off with 20 metallic electrodes and towards the end we had 50 ceramic ones with high resistive coating for beam coupling impedance issues
- Another example is the CERN EPA (electron-positron accumulator) machine. Here also ceramic electrodes with highly resistive coating were applied [1].
- For the SNS floating-ground BPMs have been designed where a DC voltage can be applied for electron cloud clearing [2]

EPA clearing electrodes

[1] A. Poncet, Experience with ion and dust clearing in the CERN AA and EPA, Proceedings of the ECL2 Workshop, CERN, Geneva, 2007

[2] L. F.Wang, D. Raparia, J.Wei, and S.Y. Zhang, Mechanism of electron cloud clearing in the accumulator ring of the Spallation Neutron Source, PRST-AB, Vol 7, 034401 (2004)

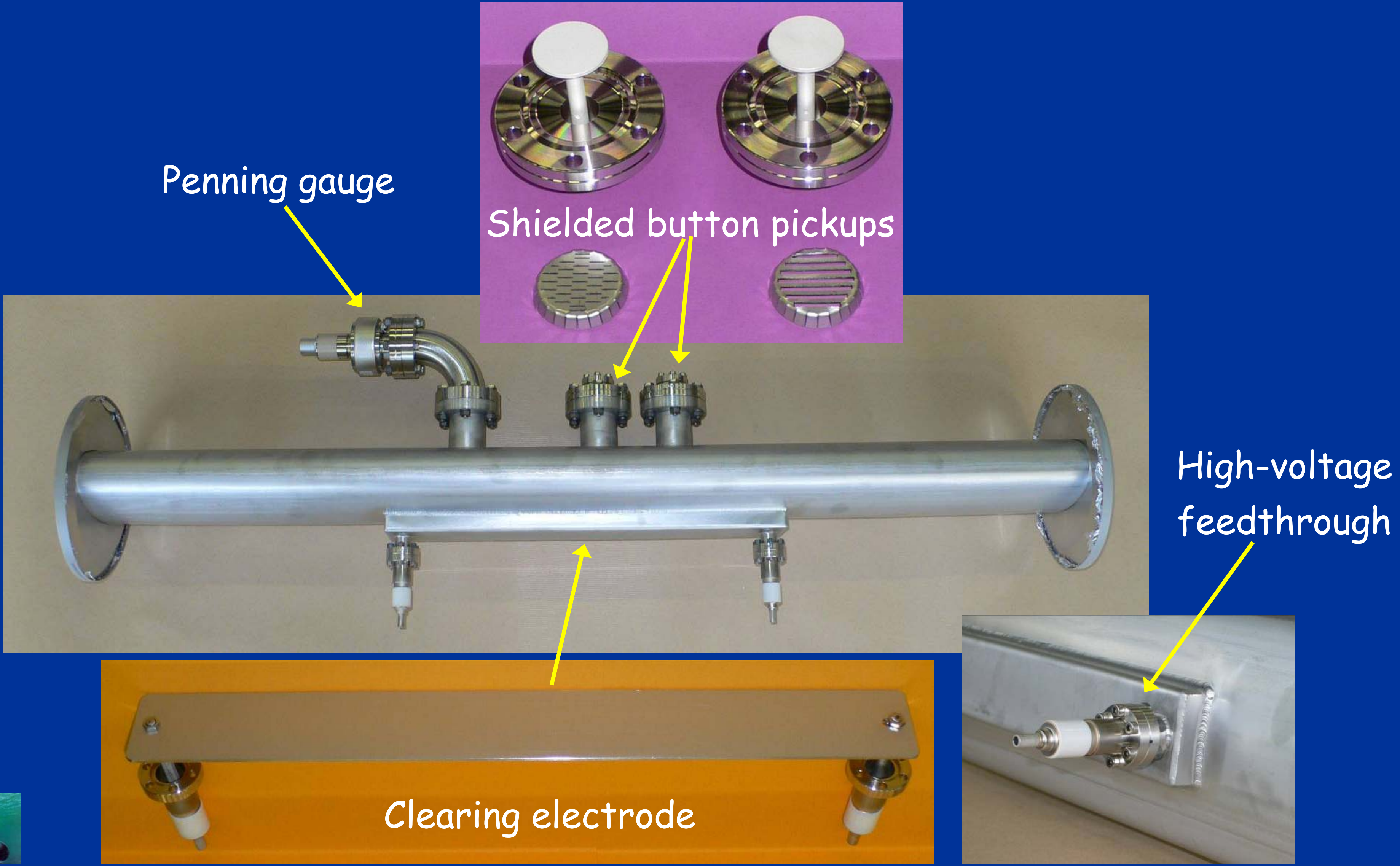
Recent experiments in the PS

- During the shutdown 2006/2007 a "simple" experiment was installed in the CERN PS [1,2]
- The goal was to research whether there is an electron cloud build-up during the last few ms to μs, when the bunches get shortened before transfer to the SPS
- The experiment comprised a shielded button pick-up, vacuum diagnostics and a small dipole magnet. A stripline electrode was added to examine the properties of clearing electrodes.

[1] http://ab-div.web.cern.ch/ab-div/Meetings/APC/2007/apc070706/EM-APC-06-07-2007.pdf

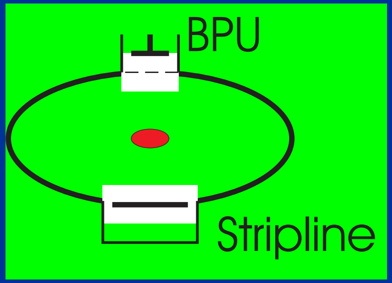
[2] http://ab-div.web.cern.ch/ab-div/Meetings/APC/2007/apc070803/TK-APC-03-08-2007s.pdf

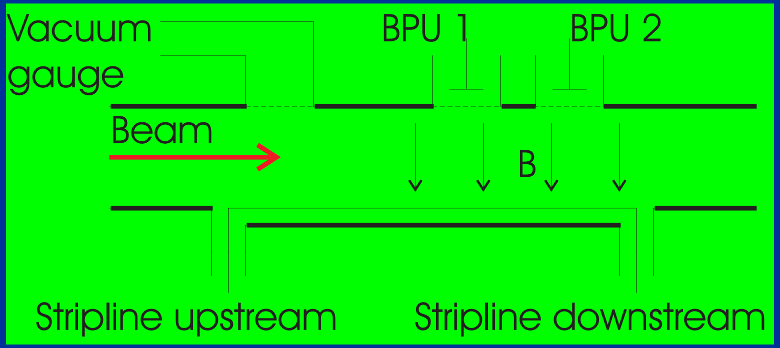
Components of the PS electron cloud setup



The PS electron cloud experiment in SS98

- PS elliptical vacuum chamber with dimensions 1050 x 146 x 70 mm.
- Special antechamber for clearing electrode without aperture reduction.
- Material: stainless steel 316 LN

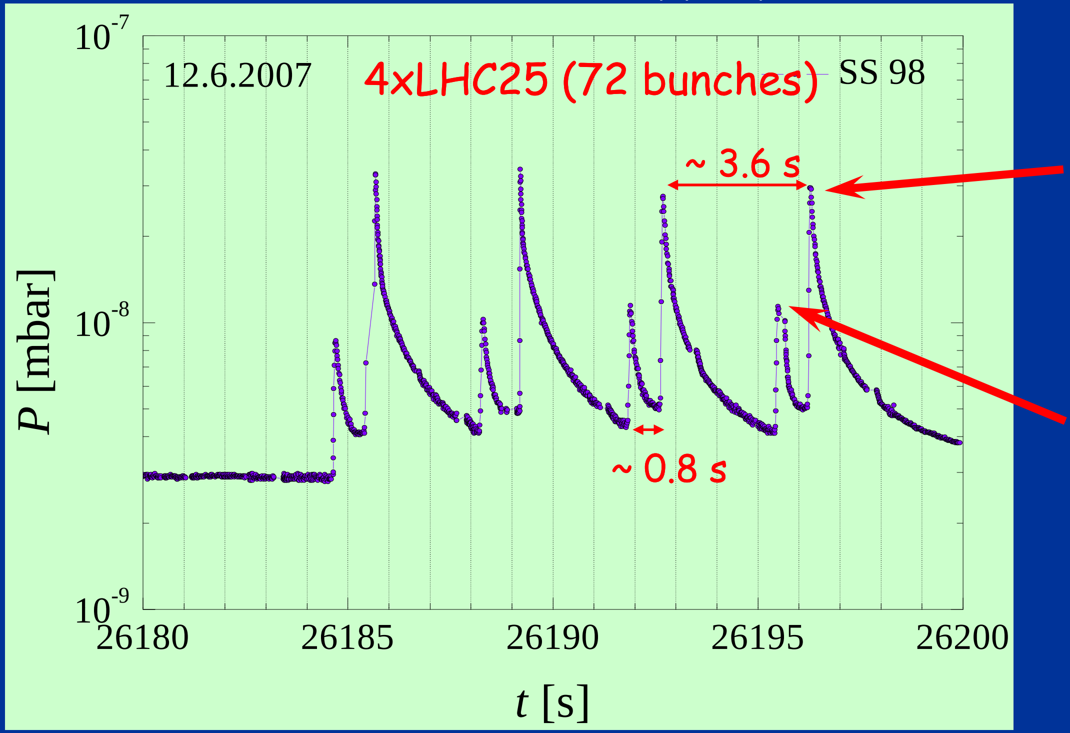




Results

- A clear electron cloud (EC) effect was found during the last ~50 ms
- Indications:
  - Vacuum pressure rise (see below)
  - Current on the shielded pick-ups
  - Clearing current on the stripline electrode
  - The effect can be switched off with an appropriate clearing voltage

Very fast pressure peaks with ~30 ms rise time, ~20 ms after onset of electron signal on the shielded buttons



ejection

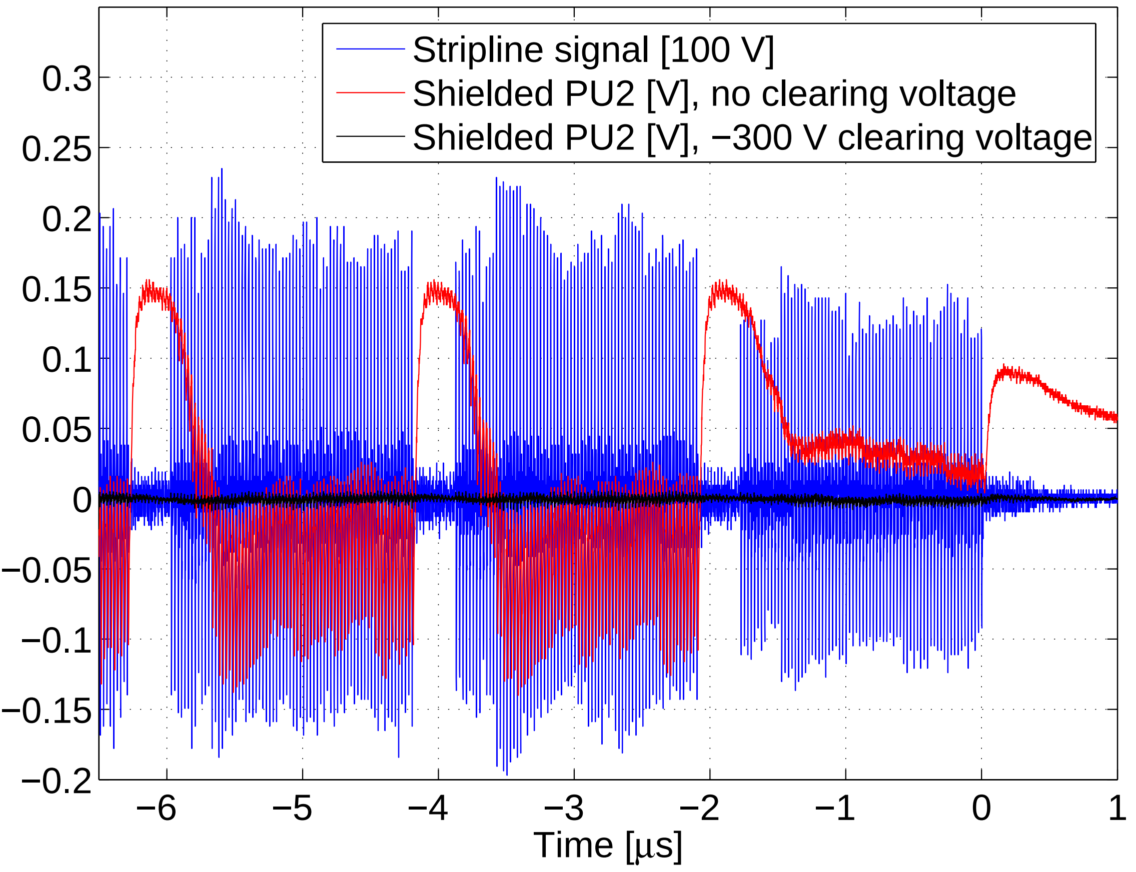
transition

Shielded PU signals

- Bias voltage on pickup: +60 V
- No magnetic field
- Last three turns before ejection plotted

- With a -300 V on the stripline no more electron cloud build-up is visible above the noise level
- The EC can be suppressed with positive clearing voltages, as well

- The clearing current on the stripline is large for positive clearing voltages (~500 µA/m) and small for negative clearing voltages (~2 µA/m)

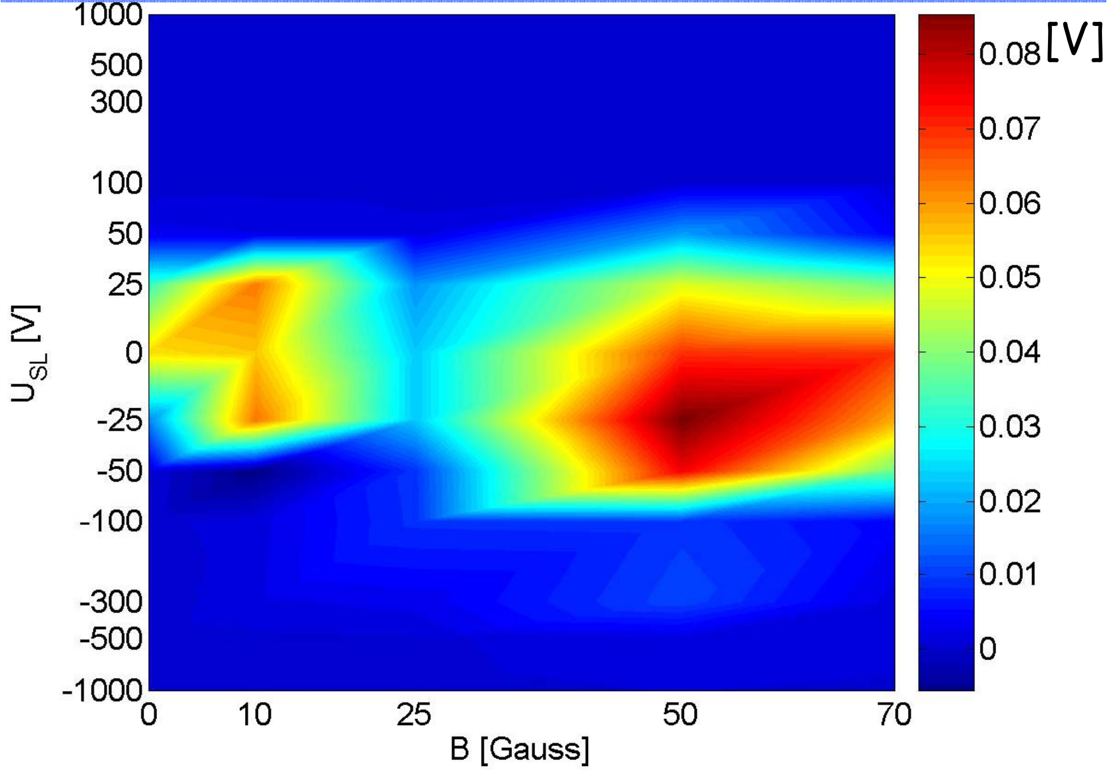


Effect of the magnetic field

- The magnetic field B and the clearing voltage U_{SL} were varied; the points where measurements were taken are marked on the axis of the plot
- The maximum EC signal on a shielded pick-up over one turn is plotted as a function of B and U_{SL}

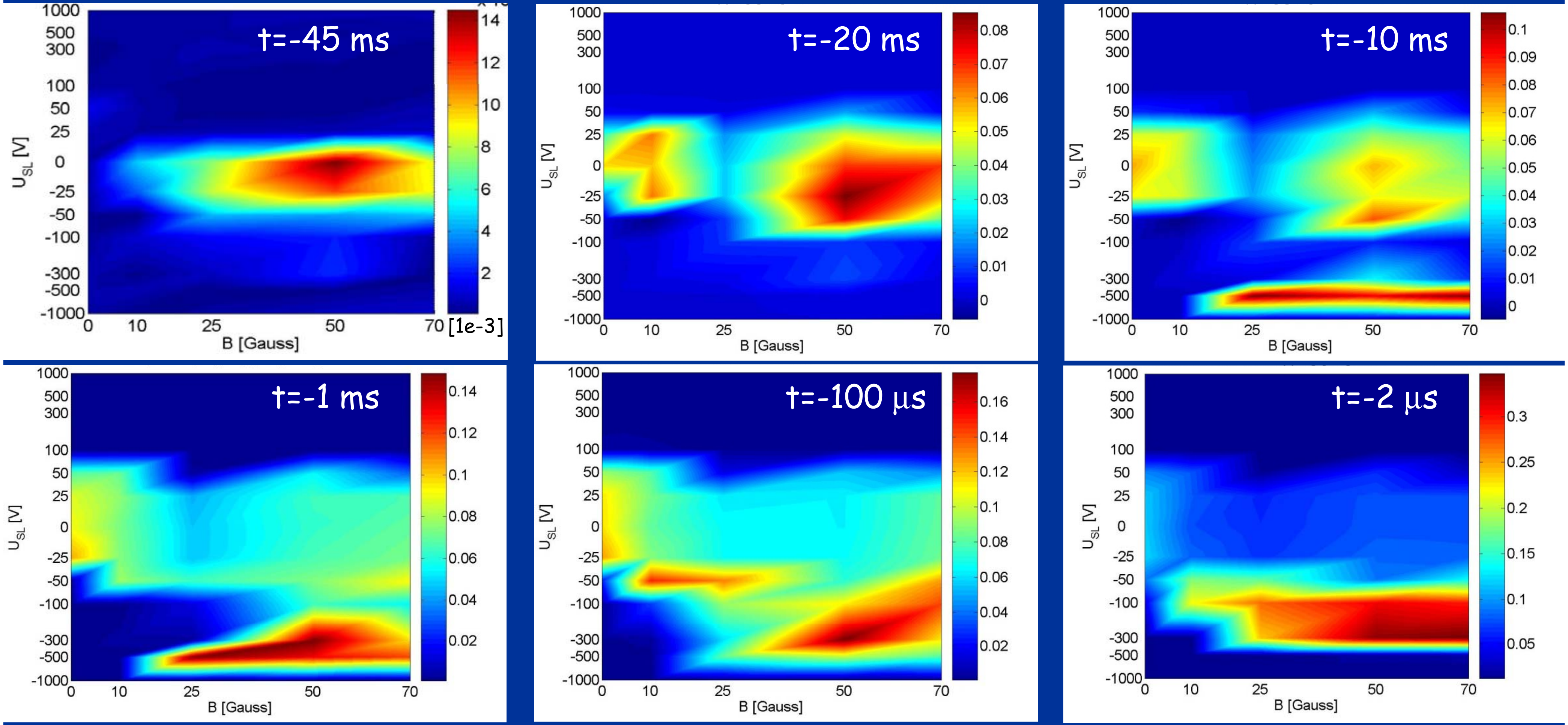
- The RF gymnastics in the PS decreases the bunch length, which allows to characterize the EC build-up as a function of bunch length (and long. profile) in one single shot
- The third bunch splitting takes place 27 to ~5 ms before ejection, giving 72 bunches with a 4σ bunch length of 14 ns.
- 5 ms to ~300 µs before ejection: Adiabatic bunch compression, bunch length decreased to 11 ns
- Last ~300 µs: bunch rotation, bunch length reduced to 4 ns.

Maximum EC signal on shielded PU1 [V], 20 ms before ejection, as a function of the magnetic field B and the clearing voltage U_{SL}



Islands with surviving EC

- EC signal from shielded PU1 plotted at different times before ejection
- Build-up starts earlier with magnetic field; Islands with large EC appear in the parameter space.
- For large enough clearing voltages ($|U_{SL}|$> 1 kV) EC suppression was found in all cases



Distributed clearing electrodes

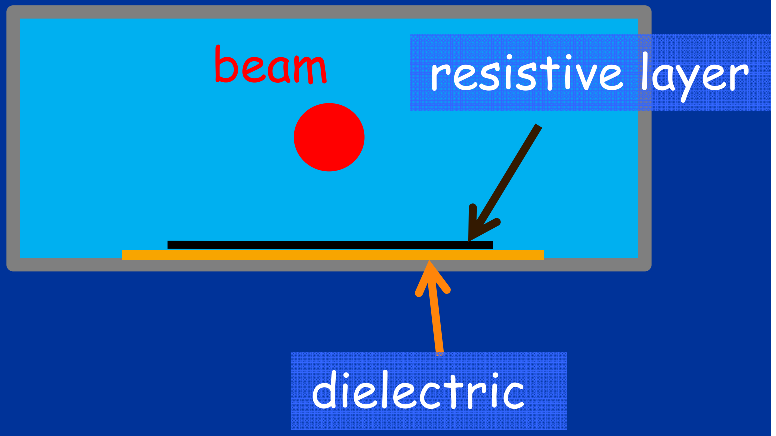
- We have seen that a stripline electrode can suppress the EC effect
- Unfortunately this works only close to the electrode. In order to suppress the EC over larger lengths of the machine we need distributed clearing electrodes
- Issues related to impedance, aperture, cost etc get more important with the electrode length. It is well known that ordinary stripline electrodes may have resonances and generally have a substantial beam coupling impedance, therefore the impedance of any proposed option has to be carefully evaluated.

Requirements for distributed clearing electrodes

- In addition to having an acceptable beam coupling impedance, clearing electrodes should fulfil as many as possible of the following points:

- Good mechanical stability
- Good vacuum properties
- Limited aperture reduction
- Good thermal contact to the beam pipe
- Low secondary emission yield (SEY)
- Electrodes should stand baking in case this is needed
- They should stand a DC voltage of the order of 1 kV
- Radiation hardness

Possible implementation



- Electrodes implemented as a resistive coating can be used to minimize the impedance. They are basically "invisible" electrodes in the sense that they are much thinner than the penetration depth and thus do not interact strongly with the beam fields. Another condition for a low coupling to the beam field is that the coating's surface resistance is much larger than the free space impedance of 377 Ω.
- Such an electrode behaves almost like a dielectric layer. The impedance was estimated analytically and by numeric simulations

- In practice, a solution could be consist of a dielectric layer made of enamel or alumina for the dielectric isolator. A resistive coating as the actual electrode is deposited on top of the dielectric.
- Such a structure in particular has good mechanic stability and good thermal contact to the beam pipe; for a thin dielectric the aperture reduction is small.

Resistive layers

- There are two conflicting requirements for the resistive layer:
    - In order to minimize the beam coupling impedance the resistivity should be high
    - However, to minimize the voltage drop on the electrode for a given clearing current the resistivity should be low
- Considering the clearing currents measured in the PS and the impedance calculations, the surface resistance should be in the range of $R_\square = 1$ to $100\ \mathrm{k}\Omega$
- The standard coating technology uses thick film paste (mainly Ruthenium oxides) which is fired at 800 deg C on alumina. Application of the thick-film paste onto enamel is being researched.

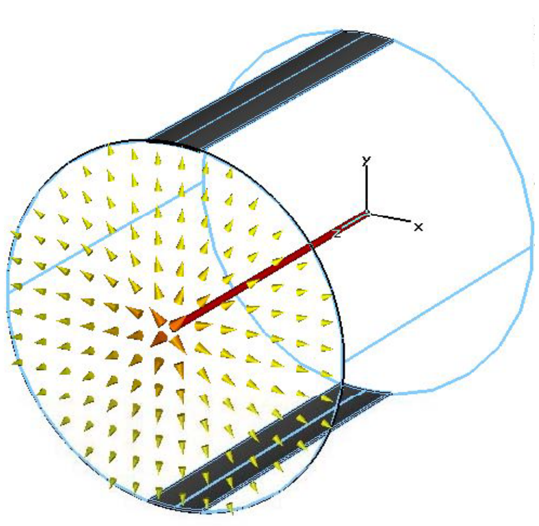
Longitudinal impedance of distributed clearing electrodes (1)

- In a first approximation the insulating and the highly resistive dielectric strips were approximated by a dielectric with permittivity ε_r
- The longitudinal impedance was estimated analytically and by simulations (CST Microwave Studio and HFSS) for a structure with rotational symmetry
- It was assumed that in analogy to a TEM line the dielectric acts mainly by introducing a phase shift => only increases the imaginary part of the longitudinal impedance Im(Z/n)

- For thin dielectric layers we get
  - Im(Z/n) is proportional to the dielectric cross-section
  - Im(Z/n) increases slowly with ε
  - Im(Z/n) is rather flat up to very high frequencies

- Estimation for one 0.1 mm thick electrode with $\varepsilon_r = 5$ all around the SPS (pipe radius 25 mm, 20 mm dielectric width): Im(Z/n)= 0.3 Ω (entire machine today: Z/n~10 Ω)

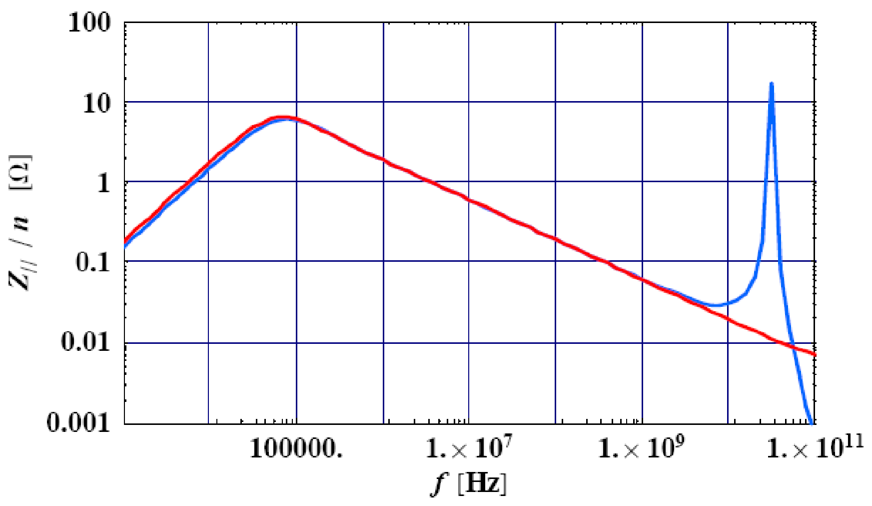
Wire simulation of two thin clearing electrodes



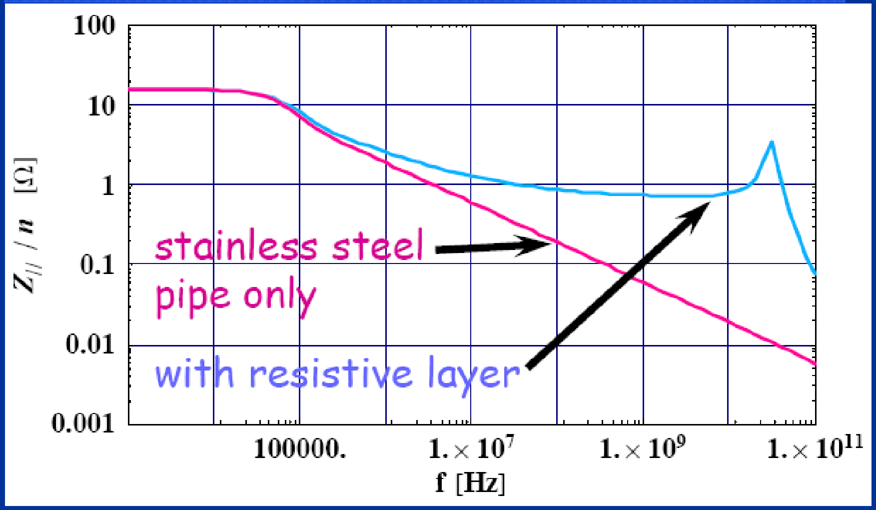
Longitudinal impedance (2)

- In a more rigorous approach the longitudinal impedance was calculated analytically for a rotationally symmetric structure
- The resistivity of the innermost structure was taken into account
- Re(Z) is not affected up to a few GHz, where the dielectric wall starts to act as a Cerenkov pick-up; the results for the increase in Im(Z) confirms the estimates on the previous page

Real part of long. impedance



Imag part of long. impedance

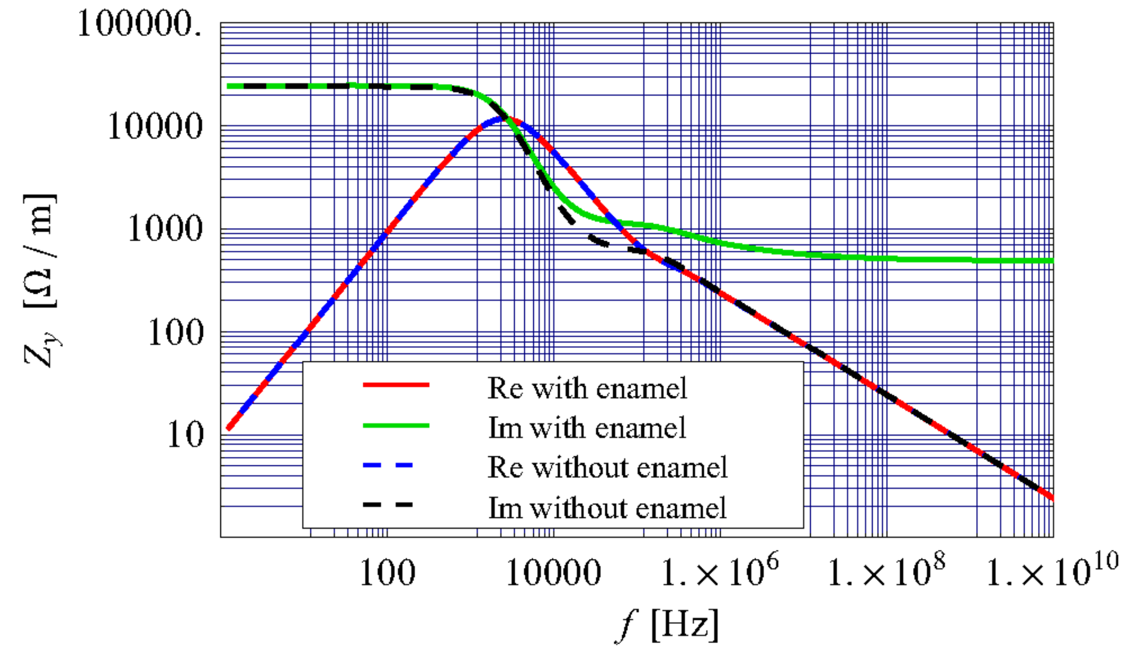


0.1 mm thick ε_r=5 dielectric inside 2 mm thick 50 mm radius stainless steel pipe, 10 µm R□=1 kΩ (ρ=0.01 Ωm) resistive layer as electrode

Courtesy: Benoit Salvant

Transverse impedance of distributed clearing electrodes

- The transverse impedance was estimated analytically for structures with rotational symmetry using the Burov-Lebedev formula and simulated using CST Microwaves Studio and HFSS [1]
- To first order the increase in Z_{TR} is purely imaginary and frequency-independent;
- Preliminary results scaled to one 0.1 mm thick centered electrode with $\varepsilon = 5$ all along the SPS (pipe radius 25 mm, electrode width 15 mm): $Im(Z_{TR,y}) = 4$ MΩ/m (entire machine today: $Z_{TR} \sim 20$ MΩ/m)



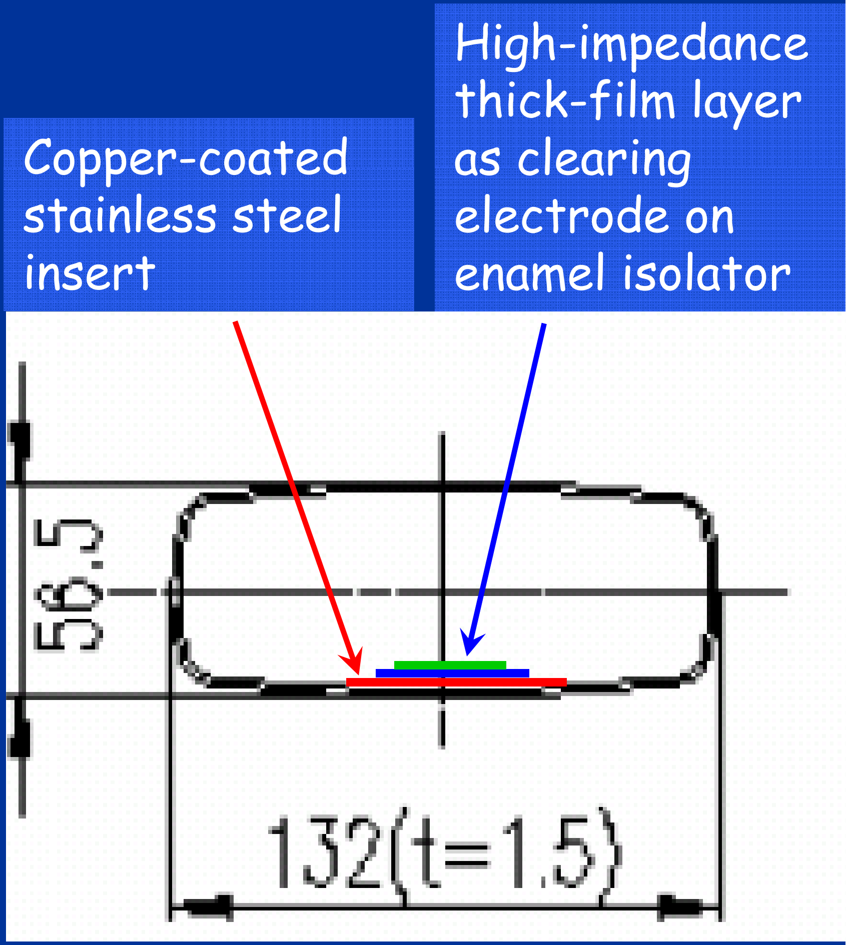
[1] T. Kroyer, F. Caspers, E. Metral, F. Zimmermann, Distributed electron cloud clearing electrodes, Proceedings of the ECL2 Workshop, CERN, Geneva, 2007

Courtesy: E. Metral

Potential solution for the SPS: an insert

- Material: thin stainless steel sheet of about 0.5 mm thickness
- Can be copper-coated for impedance and contact issues
- In the center an about 20 mm wide and ~0.1 mm thick enamel strip or another suitable material as isolator
- On top of the dielectric a ~15 μm highly resistive thick film layer acts as an "invisible" clearing electrode

- The strip can be spot-welded to the beam pipe at the ends or at regular distances along the chamber (requires spot-welding inside the chamber)



Copper-coated stainless steel insert

High-impedance thick-film layer as clearing electrode on enamel isolator

Conclusion

- Clearing electrodes have been used in several machines for ion and electron cleaning
- In the PS electron cloud cleaning was achieved with a 40 cm long stripline electrode biased at ~1 kV
- The challenge is to apply such electrodes over longer section of a machine, which exacerbates impedance and other issues
- A highly resistive coating has a low longitudinal and transverse impedance; in practice resistive layers an enamel, alumina or other dielectrics can be used
- There is ongoing work on the practical implementation of such electrodes

testing the deposition of enamel strips inside a beam pipe...